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The Use of Laser Diffraction in Measuring the Effect of Suspended Sediment on the Shell Growth of Mussels, Mytilus edulis

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THE USE OF LASER DIFFRACTION IN MEASURING THE EFFECT OF SUSPENDED SEDIMENT ON THE SHELL GROWTH OF MUSSELS, *Mytilus edulis*

by

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ABSTRACT

The increasing use of nearshore marine areas for shellfish culture combined with frequent disturbance of bottom sediments through dredging and associated activities has underscored the need for information on the effects of suspended sediments on bivalve growth. Using a laser diffraction technique, shell growth of blue mussels, Mytilus edulis, was monitored daily over five days. Two groups of animals were used; a control, which was offered laboratory-grown phytoplankton only, and an experimental group exposed to the same ration but with marine sediment added. Analyses of variance indicated that exposure to an average daily concentration of 225 ± 10.9 (S.E.) mg/l of suspended particulate material (SPM) did not markedly reduce mean shell growth rate (P=0.05), although a significant trend of diminished growth was noted in the exposed population when analysed by the Wilks-Lambda test (P=0.05). Mean daily shell length increases were 46 and 58 microns for the SPM exposed and control groups respectively. This method of measuring incremental shell deposition in mussels could prove useful in testing the short-term effects of various environmental conditions on growth. Details of the laser diffraction method are provided.

RÉSUMÉ

Sushko, H. and K. R. Freeman. 1991. The use of laser diffraction in measuring the effect of suspended sediment on the shell growth of mussels, Mytilus edulis. Can. Manuscr. Rep. Fish. Aquat. Sci. 2121: 28 p.

L'utilisation accrûe des zones côtières pour la conchyliculture jumelée à de fréquentes perturbations de sédiment de fond causées par le dragage ou autres activités connexes ont rendu nécessaire l'évaluation de l'effet de sédiment en suspension sur la croissance des bivalves. La croissance des coquilles de moules bleues, Mytilus edulis, a été mesurée quotidiennement pendant cinq jours en utilisant une technique de diffraction au laser. Deux groupes d'animaux ont été utilisés; un groupe contrôle, nourri avec du phytoplankton cultivé en laboratoire, et un groupe expérimental reçevant un mélange de phytoplankton et de sédiment en suspension. Une analyse de variance nous a démontré que l'exposition quotidienne d'une concentration moyenne de 225 ± 10.9 (E.S.) mg/l de matière particulaire en suspension (MPS) n'avait pas réduit le taux de croissance des coquilles (P=0.05); toutefois lorsque les résultats furent analysés par le test de Wilks-Lambda, une réduction significative à été notée (P=0.05). Tous les jours la croissance moyenne des coquilles était de 46 à 58 microns pour le groupe exposé au MPS et le groupe contrôle respectivement. Cette méthode dont nous nous sommes servi pour mesurer l'accroissement quotidien des coquilles de moules pourrait devenir très utile pour vérifier les effets à court terme que pourraient avoir diverses conditions environnementales sur la croissance des bivalves. Les renseignements sur la technique de diffraction au laser y sont incluses.

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INTRODUCTION

Growing concern among aquaculturists over the integrity of inshore environments has recently focused attention on the impact of high concentrations of suspended particulate material (SPM) on the biology of commercial species. Domestic or industrial effluent discharges, ocean dumping and dredging may result in high particle loading which, in turn, may adversely affect shellfish production at aquaculture sites (Appleby and Scarratt 1987). Although natural bivalve populations are known to survive high particle loads resulting from natural phenomena such as heavy runoff, tidal mixing and storms, the high density of cultured bivalves, as compared to natural populations, may increase their vulnerability to elevated concentrations of deleterious materials (Heral 1987). In order to determine acceptable turbidity levels for shellfish culture sites, information is required on the effect of high particle concentrations and exposure times on bivalve production.

Investigations of SPM effects on mussels have left a confused picture. Kiørboe et al. (1980) indicate that Mytilus edulis shows increased growth at concentrations approaching 25 mg/l and can adapt to 55 mg/l SPM. Kiørboe et al. (1981) concluded that the presence of suspended silt in the diet is a prerequisite for M. edulis to attain maximum growth rate. Purchon (1937) however, reported that concentrations of SPM up to 440 mg/l had no effect on mussels. Collinson and Rees (1978), investigating major mortalities in cultured M. galloprovincialis, determined that the problem was caused by reduced oxygen during exposure to 180 mg/l SPM resulting from nearby dredging. Reports such as these, while contributing to a growing background knowledge of the effect of SPM on mussels, have not provided the kind of information needed by legislators attempting to manage the nearshore environment. A 1985 dispute at Neguac, New Brunswick, involving mussel mortalities in a lease exposed to suspended dredge materials, resulted in litigation, which emphasizes the urgent need for more information on this subject.

This study attempts to determine if SPM can interfere with mussel physiology to the extent that there is an immediately detectable change in growth rate. Using laser diffraction, the growth of live mussels can be measured without risk of damaging shells or adversely affecting growth or survival (Strømgren 1975). This technique was employed with M. edulis to test the hypothesis that high SPM levels would quickly affect daily growth rates.

MATERIALS AND METHODS

DEVELOPMENT OF THE LASER DIFFRACTION METHOD

Background

Bivalve growth has two components: shell growth and soft-tissue proliferation. Shell growth in molluscs can be defined as an increase in linear dimension along a particular axis and for this study, length (umbo to posterior edge) was used. Methods for measuring soft tissue growth destroy the animal, whereas shell dimension changes can be obtained with minimal disturbance. Traditional measuring techniques using sliding rule micrometers may damage mollusc shells; moreover, they are only sensitive to several days of cumulative growth. Optical techniques can be highly accurate, particularly the laser diffraction technique (S.D. = 3 microns) first applied by Strømgren (1975, see Figure 1). In this procedure, a single mussel is affixed to a frame and a thin plate or tab of inert material is fastened close to the posterior edge of the shell thus forming a narrow slit. When a laser beam is directed through the slit (whose width approximates the wave length of light used) and onto a screen, a diffraction pattern is produced at right angles to the orientation of the slit. Separation of adjacent light maxima in the pattern is inversely proportional to the slit width. As the mussel grows there is a reduction of slit width and a proportional increase in the distance between adjacent maxima.

Strømgren (1975) and Strømgren and Cary (1984) used both silver and plastic for the aperture tabs. A small neon-helium gas laser with a wavelength of $6.328 \cdot 10^{-7}$ m and an output of 0.8 mW was used which poses no health risk for the operator (Strømgren 1975). By measuring the distance between the centers of two adjacent light spots, or light maxima (Figure 2) of this diffraction pattern, the slit aperture (a) was calculated as follows (Strømgren 1975):

$a = (\lambda \cdot s) / d$ where: s = the distance from the slit to the diffraction pattern;
d = the distance between two adjacent light maxima;
λ = the wavelength of the laser light

The diffraction pattern can be photographed and the average distance between any two adjacent light maxima measured from the developed photograph under magnification. The system used by Strømgren and Cary is shown in Figure 1, and modifications used by the authors (Figure 3) are described below.

Slit Aperture Establishment

In the present study, a bed was formed of a soft putty made of marine grade epoxy resin and microspheres. After the bed hardened, a space was carved into it, to conform to the shape of the shell, and the mussel was then glued into place with a cyanoacrylate glue. Tabs used in this experiment were of a 316 grade, stainless steel resistant to salt water and sandblasted to reduce light reflected to the operator. In order to orient the tab edge in the same plane as the growing edge of the mussel shell, the tab was bent to form an "S" shape (Figure 3). Using stainless steel bolts, each tab was positioned at the same horizontal plane as the shell edge. Tab height was adjusted solely by turning the bolt nearer to the mussel.

Strømgren (1975) examined widths of slit openings exposed to a temperature range of 8 to 22 C and observed minimal effects. Thermal expansion was not a factor in this study, however, as mussels were held in 20 C water and measured at room temperature (20 - 22 C). Mussels can marginally shift position by tightening the byssus, but neither the degree of drag nor the activity of the foot was sufficient to give a measurable change in slit widths (Strømgren, 1975).

Recording And Measuring Diffraction Patterns

Bilaterally symmetrical diffraction patterns were recorded directly on photographic film using a 35 mm single lens reflex camera with the lens removed (Figure 3). The camera opening permitted recording of only slightly more than

half of each pattern (Figure 2). Film was then developed and by using a dissecting microscope equipped with an ocular micrometer, a span of 10 inter-maxima distances (d) in each diffraction pattern was measured per animal per day. A backup record was made by projecting the diffraction pattern for each animal onto paper and measuring the span of 10 intermaxima distances marked on the paper onto which the diffraction image was projected.

EXPERIMENTAL SETUP AND CONDITIONS

General

One hundred, three month old mussels (15-30 mm in length) were taken from a culture line at Mountain Island Hatchery at Upper Blandford, Nova Scotia, in October, 1988. Four subgroups of ten animals each were haphazardly selected and used in two lots of twenty as the experimental and control groups respectively. The experimental setup comprised two principal components: the combined food/sediment air-lift delivery system and grazing chambers (MacDonald jars, designed for salmon egg culture), and the laser source and recording apparatus. Four food/grazing chamber combinations (Figure 4) were established; the two control and two experimental chambers each contained ten affixed mussels suspended vertically by cords around the wall of the chamber. Mixtures of the marine diatom Chaetoceros gracilis and the flagellate Isochrysis galbana were slowly fed to the control mussels over a period of several hours each day of the experiment; similar mixtures, with sediment added, were fed to the experimental animals. Time constraints prohibited establishing a food/sediment control without animals to test for settlement of sediment versus its removal by filtration.

The most important precautions taken to ensure accuracy were to make the slit as stable as possible and to determine that the valves were firmly closed (Strømgren 1975). Throughout the experiment distances between the tabs and growing edges of mussel shells measured from 0.10 mm to 0.60 mm. Although the stainless steel edge is linear and the edge of the shell is curved, it has been observed by Strømgren (1975) that a usable diffraction pattern can be obtained only when the tangent of the shell edge is parallel to the stainless steel edge; therefore, re-positioning the same part of the slit in the laser beam is easy. Any error caused by incompletely closed shells was reduced by tapping the shells to ensure closure and by noting changes in diffraction patterns during such irritation.

Food/Sediment Supply And Growth Chambers

Determining effects of SPM on marine animals confronts the problem of maintaining particles in suspension. Moreover, Moore (1977) suggests that the effects of water movement per se on animal metabolism and behavior can be significant, thus sea water controls that are clear, static, and contain nutrients only are necessary to satisfy these criteria. Due to both temporal and logistic constraints this additional control was not used.

Phytoplankton and phytoplankton/sediment mixtures were held in 20 l glass carboys supported on plywood boxes over magnetic stirrers and delivered to the grazing chambers by means of an air-lift mechanism (Figure 4). The lower end of the air-lift was a cylindrical "bell", 65 mm long by 20 mm (i.d.) and connected by a 4 mm (i.d.) glass tube through the bung to a silica drying tube connector. When assembled, the bell just cleared the stirring bar. An air "injector" was made from 4 mm (i.d.) glass tubing and attached to the bell as shown (Figure 4) and to the incoming air by plastic tubing. Air flow to a filled carboy was adjusted with a screw-type hose clamp so that food (or food/sediment mixture) was delivered at the initial rate of around 800 ml per hour; 70-75% of the carboy contents were delivered in 20 hours.

The combined air-lift and recycling system as well as the sediment/faeces separator (Figure 4) maintained algae and inorganic particulate matter in an evenly distributed suspension (despite being somewhat slow in turnover rate). Aeration was thus additionally provided outside the grazing chambers without disturbing the animals.

Sediment was intertidal silt/clay obtained from Burntcoat Head, Minas Basin, Bay of Fundy and was treated as follows: seawater was first pre-mixed with the combined algal cultures in the ratio 9:1. One part of the sediment mix was added to nine parts algae/seawater, mixed by a mechanical paint-stirrer for one-half hour then allowed to settle for a further half-hour. The food/suspended sediment mixture was then siphoned off and kept aerated in a carboy. Concentrations of suspended particulate matter (SPM) were measured using the procedures in Standard Methods For the Examination of Water and Wastewater (Sixteenth Edition, 1985).

Daily Protocol

For each day of the experiment, all slit apertures were set at approximately 0.5 mm, diffraction patterns projected, and the individual tab to mussel distances recorded; the mussels were then placed in the appropriate grazing chamber. Each chamber was 80% filled with filtered sea water, then topped up with either algae or algae/sediment mix. Air-lifts were adjusted to an initial output of roughly 800 ml per hour, and the stirrers activated.

Following half an hour of algae/sediment injection by the air lift system, the initial (time 0) samples for SPM analysis were taken by siphoning fluid from the centers of the two grazing chambers containing sediment. Final samples were taken just prior to the end of a one-day (24 hour) run. Mussels were then retrieved individually, to minimize aerial exposure, diffraction patterns were recorded and slits readjusted and measured where necessary. Within three minutes of retrieval, each animal was returned to freshly-filtered sea water at 20 C in the grazing chambers and the process started again.

Initial lengths of each animal were recorded and daily individual growth increments were calculated. Means, standard errors, and standard errors times 't' were determined for each replicate, treatment, and for shell lengths by day by treatment. These data were analyzed by applying the repeated measures, univariate analysis of variance (ANOVA), the Wilks-Lambda test and Shapiro-Wilks test for normalcy (by treatment) from the general linear model procedure, SAS package, version 6.03.

RESULTS

SHELL GROWTH

Despite care taken to ensure solid attachment of animals to their mounting frames, there were gluing failures thus reducing the number of mussels per treatment to 15. Initial shell lengths and growth increments are compiled in Table 1. Statistics on the daily shell lengths by treatment are found in Table 2, and on the daily growth increments in Table 3.

As a first step in comparing mean differences between control and experimental groups, the repeated measures, univariate analysis of variance (ANOVA) was used (Table 4). The null hypothesis that there was no difference in growth between the two treatments was accepted since the probability (p) was 0.3896 (higher than the significance level of 0.05; see also Figure 5). Similarly, the null hypothesis that there was no difference in shell growth between replicates within a treatment was also acce ted (p=0.0532) and is reflected in Figure 6(i) and 6(ii). These two statistical results were regarded as preliminary, principally because of the short duration of the experiment but also because comparisons of means can mask small yet potentially significant trends which accumulate in an individual over time.

Accordingly, the Wilks-Lambda test was applied to the data and yielded the following analyses of growth rates of individuals over time:

i) The null hypothesis of no time effect - no difference in daily growth over time, both treatments combined (but not compared) - was rejected (P=0.0001) indicating a mean change in rate of individual growth over time. Accordingly, Figure 7 displays significant differences among the daily rates irrespective of treatment.

ii) The null hypothesis of no time-by-treatment effect (no difference in growth over time between treatments) was also rejected as the probability level (0.0387) was again less than 0.05, showing a difference between the control and experimental treatments. Day five treatment comparison in Figure 7 demonstrates this difference.

iii) The null hypothesis of no time-by-treatment-by-replicate effect within treatments was accepted (p=0.3158); within each treatment, animals in the two grazing chambers grew in a similar fashion. This is supported by the second part of the ANOVA and by Figure 6(i) and 6(ii).

SUSPENDED PARTICULATE MATERIAL

Simple daily SPM averages by replicate, a daily average over replicates, and an average SPM with standard errors over all days and replicates are presented in (Table 5). Throughout the five-day experiment the overall concentration of SPM averaged 225 $\pm$ 10.9 (S.E.) mg/l, with a range of 147 to 357 mg/l and a daily average range from 193.8 to 264.8 mg/l.

DISCUSSION AND CONCLUSIONS

Suspended sediments in seawater are derived from: (a) suspended river material, (b) aeolian material, and (c) colloid or solid precipitated substances (Moore, 1977). Their relative concentrations in the sea will obviously vary along the coast and with distance from land. Insoluble particles in the sea in time become sediment; the duration depends on particle size and water depth. This study dealt with finer grained sand and clay particles that remain in suspension long enough to exert a potentially negative impact on shellfish.

Turbidity in nature is largely attributable to clay-sized particles, which are relatively efficiently removed by bivalves. As ingested particles are discriminated on the basis of size and weight rather than on nutritional quality, clay-sized particles cause a dilution or reduction of food quality. Thus, high SPM might provoke the utilization of stored reserves, resulting in decreased condition and shell growth rate. Suspended organic particles may also reduce dissolved oxygen concentration due to the high biochemical oxygen demand, thus adding to an organism's stress (Moore 1977). Two mechanisms have been postulated (Foster-Smith 1975) by which the amount of material ingested is reduced when SPM concentrations increase: first, by lowering filtration rate to reduce the volume of water cleared, and/or by increasing the proportion of material rejected. It has been demonstrated repeatedly that ingestion of suspended material by bivalves continues in turbid conditions (Moore 1977). For example, Dodgson (1928) reported that M. edulis continued to feed, and pass a maximum of faeces, when immersed in water so turbid with added river mud, clay, chalk, flour, and similar materials, that the mussels were invisible at a depth of two to three inches.

There are many demonstrated instances where different species have adapted to specific conditions which contribute to their ecological separation in the field (Moore 1977). M. edulis, being an intertidal to subtidal, coastal as well as estuarine species and therefore subject to highly variable conditions is, among Lamellibranchs, comparatively tolerant of turbidity and siltation. It thrives in conditions inimical to the majority of suspension-feeders (Moore 1977), although there are clear limits. For example, Purchon (1937), reported that blue mussels died after a thirteen day exposure to suspended solids at a concentration of 1,220 mg/l. The extreme case of mortality aside, shell growth in mussels is reduced in waters laden with certain particles (Gruffydd 1974), which may be due to the mantle margin contracting away from the shell edge under a bombardment by mineral grains (Rhoads and Pannella 1970). Moreover, the shell edge may also be directly abraded under the influence of sufficiently energetic wave or current action (Walne 1958). When feeding in high concentrations of suspended solids, M. edulis maintains a steady rate of ingestion when the maximum or satiation level is reached, but with increased production of pseudofaeces (Moore 1977). Theisen (1972) has observed direct ingestion of organic and inorganic material by mussels using their foot to clean the outer shell surface. Particles were subsequently transported by ciliary action into the mantle cavity. Thus, efficient shell-cleaning behavior and pseudofaecal expulsion, contribute to the mussel's success in surviving turbidity and siltation. Finally, despite its byssal attachment, M. edulis is not immobile (Paine 1974) so that, in certain circumstances, it may also escape adverse conditions (Moore 1977).

This attempt to measure the effects of suspended particulate material on mussel shell growth through the use of the laser diffraction technique is a response to the need for bioassays which can ascertain reasons for stock damage, or demonstrate the presence of conditions unfavourable for mussel culture. Unfortunately, analysis of the data demonstrated some ambiguity in that a five day exposure to an average concentration of 225 mg/l of SPM was insufficient to cause a marked reduction in shell growth rate, although the data did exhibit a trend of reduced growth in the sediment-exposed population (Table 3). This marginal decrease notwithstanding, the result confirms work by Moore (1977) that blue mussels will survive and grow in elevated concentrations of SPM.

The marginal sensitivity to SPM demonstrated by these animals, combined with their hardiness, identifies blue mussels as being suitable for toxicity evaluations of both short and long-term duration. As toxicants can affect bivalves by interfering with shell deposition, this effect is the basis for toxicity tests of varying duration using appropriate numbers of test organisms

(Standard Methods for the Examination of Water and Wastewater, Sixteenth Edition, 1985). Although logistic constraints imposed by small grazing chambers meant that the numbers of animals used did not provide the highest analytical precision, the number (fifteen) used in each treatment in the final analysis was nonetheless above the minimum recommended in Standard Methods For The Examination Of Water And Wastewater (1985). We are satisfied that the general comparative cumulative growth tendencies of the control and experimental groups are not artifacts, yet we cannot explain the change in relative rates on the last day (Figure 7). It is possible that subtle experimental differences were at work - either in the physical setup or in the food or food/sediment mixture. Indeed, the abnormally distributed growths on the first day in both experimental and control groups suggest a handling effect (Table 3). The remaining abnormally distributed growth periods (days 3 and 4) were confined to the experimental group which could signal an effect of the sediment. There is also the possibility that a certain short-term acclimatization occurred in the first four days, and that the final day's growth signalled adaptive change in the physiology of the mussels. It is not certain whether the synergistic effect of combined algae and sediment on growth noted by Kiørboe et al. (1981), requires an initial period of adaptation by the animals. A longer test is clearly in order as growth perturbations could then be put into proper perspective while at the same time increasing the likelihood of detecting subtle differences between the groups. Frequent sampling of SPM throughout an experiment would also provide a better measure of the concentration and of its uniformity. Raising the level of SPM in the experimental group might also yield greater growth differences compared with controls, even in a five-day test.

RECOMMENDATIONS

1. Increasing the tubing diameter (hence flow rate) from the grazing chamber to the air-lift recirculation/faeces trap system would reduce sedimentation in the chamber and increase faeces entrapment outside of it.

2. Improve the method of gluing mussels to their mounts to reduce experimental failures.

3. Peristaltic pumps, rather than airlifts, would provide a more steady supply of food and/or test substance to experimental animals.

4. Due to the short duration of the experiment, coupled with the necessarily small numbers of test animals used, the laser diffraction technique should be re-applied in other investigations involving: (a) larger numbers of animals, (b) other Lamellibranchs having a smooth shell edge, (c) a longer duration of exposure to suspended sediment, (d) other types of material, including noxious chemical substances, (e) higher concentrations of sediments than those used in this study, and (f) sediments defined as to particle size/shape and organic content.

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REFERENCES

Appleby, J.P. and D.J. Scarratt. 1989. Physical effects of suspended solids on marine and estuarine fish and shellfish, with special reference to ocean dumping. A literature review. Can. Tech. Rep. Fish. and Aquat. Sci.: No. 1680. 33 p.

Bayne, B. 1976. Physiology, p. 121-206. In : B.L.Bayne (Ed.). Marine Mussels - Their Ecology and Physiology. Cambridge University Press, Cambridge, England. 506 p.

Collinson, R.I. and C.P. Rees. 1978. Mussel mortality in the Gulf of La Spezia, Italy. Mar. Pollut. Bull., 9: 99-101.

Dodgson, R.W. 1928. Report on mussel purification. Min. of Agricult. and Fish., Fish. Invest., Ser. 2, Vol. X, No. 1. 498 p.

Foster - Smith, L. 1975. The effect of concentration of suspension and inert material on the assimilation of algae by three bivalves. J. mar. biol. Ass. U.K., 55: 411-418.

Gruffydd, L.D. 1974. The influence of certain environmental factors on the maximum length of the scallop, Pecten maximus L. J. Cons. int. Explor. Mer., 35(3): 300-302.

Heral, M. 1987. Evaluation of the carrying capacity of molluscan shellfish systems. In : Shellfish Culture Development and Management: International Seminar in La Rochelle (France), March 4-9, 1985. IFREMER. 410 p.

Kiørboe, T., F. Møhlenberg and O. Nøhr. 1980. Feeding, particle selection and carbon absorption in Mytilus edulis in different mixtures of algae and resuspended bottom material. Ophelia, 19: 193-205.

Kiørboe, T., F. Møhlenberg and O. Nøhr. 1981. Effect of suspended bottom material on growth and energetics in Mytilus edulis. Mar. Biol. 61: 283-288.

Moore, P. G. 1977. Inorganic particulate suspensions in the sea and their effects on marine animals. In : Harold Barnes (Ed.). Oceanogr. Mar. Biol. Ann. Rev., 15: 225-263.

Paine, R.T. 1974. Intertidal community structure: Experimental studies on the relationship between a dominant competitor and its principal predator. Oecologia (Berl.), 15: 93-120.

Purchon, R.D. 1937. An ecological study of the beach and the dock at Portishead. Proc. Bristol Nat. Soc., 8: 311-329.

Rhoads, D.C., and G. Panella. 1970. The use of molluscan shell growth patterns in ecology and paleoecology. Lethaia, 3: 143-161.

Spector, P., J.H. Goodnight, G.P. Sall and W.S. Sarle. 1987. The general linear model procedure. p. 549-640. In : R.C. Luginbuhl and S.D. Schlotzhauer. (Ed.).

SAS/STAT guide for personal computers. SAS Institute Inc., Cary, N.C.

Standard Methods For the Examination of Water and Wastewater. 1985. Sixteenth Edition; American Public Health Assoc., Washington, D.C. 1268 p

Strømgren, T. 1975. Linear measurements of growth of shells using laser diffraction. Limnol. and Oceanogr., 20 (5): 845-848.

Strømgren, T., and C. Cary. 1984. Growth in length of Mytilus edulis L. fed on different algal diets. J. Exper. Mar. Biol. Ecol., 76: 23-34.

Theisen, B.F. 1972. Shell cleaning and deposit feeding in Mytilus edulis L. (Bivalvia). Ophelia, 10: 40-55.

Walne, P.R. 1958. Growth of oysters (Ostrea edulis L.) J. mar. biol. Ass. U.K., 37: 591-602.

MUSSEL NUMBER	TREATMENT	REPLICATE	DAY 0 SHELL LENGTH	DAY 1 INCREASE	DAY 2 INCREASE	DAY 3 INCREASE	DAY 4 INCREASE	DAY 5 INCREASE
1	1	1	19.400	0.006	0.033	0.083	0.005	0.098
2	1	1	24.630	0.030	0.109	0.006	0.100	0.100
3	1	1	16.570	0.026	0.013	0.051	0.000	0.058
4	1	1	16.730	0.009	0.081	0.065	0.054	0.025
5	1	1	21.650	0.007	0.021	0.019	0.003	-0.010
6	1	1	21.560	0.030	0.109	0.069	-0.042	0.013
7	1	2	22.420	0.006	0.110	0.025	0.010	0.000
8	1	2	23.290	0.011	0.070	0.063	0.035	0.098
9	1	2	22.610	0.070	0.119	0.092	0.088	0.122
10	1	2	23.240	0.112	0.023	0.057	0.060	0.195
11	1	2	26.480	0.017	0.159	0.003	0.069	0.060
12	1	2	20.430	0.068	0.085	0.033	0.079	0.160
13	1	2	23.600	0.012	0.129	0.005	0.063	0.013
14	1	2	24.660	0.013	0.133	0.030	0.121	0.098
15	1	2	23.520	0.043	0.133	0.055	0.114	0.087
16	2	1	24.130	0.023	0.040	0.046	0.052	0.115
17	2	1	22.040	0.031	0.056	0.006	0.023	0.103
18	2	1	21.710	0.021	0.037	0.016	0.107	0.079
19	2	1	24.600	0.011	0.046	0.062	0.004	0.159
20	2	1	24.830	0.014	0.047	0.009	0.068	0.111
21	2	1	21.710	0.000	0.014	0.004	0.033	0.053
22	2	1	27.080	0.074	0.116	0.010	0.117	0.110
23	2	2	23.700	0.015	0.052	0.004	0.011	0.078
24	2	2	24.940	0.032	0.070	0.005	0.025	0.146
25	2	2	24.410	0.018	0.012	0.002	0.003	0.028
26	2	2	24.190	0.024	0.023	0.014	0.021	0.077
27	2	2	24.330	0.008	0.061	0.052	0.067	0.124
28	2	2	23.820	0.027	0.062	0.034	0.068	0.072
29	2	2	23.170	0.024	0.096	0.076	0.018	0.120
30	2	2	25.820	0.016	0.003	0.006	0.017	0.024

Table 1. Initial shell lengths and daily growth increments in millimeters, control (treatment 1) and experimental (treatment 2) groups.

MUSSEL GROUP (TREATMENT)	STATISTIC	DAY 0	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
CONTROL	MEAN	22.053	22.083	22.172	22.216	22.266	22.340
	STD. ERROR	0.722	0.723	0.730	0.727	0.733	0.736
	S.E. (t)*	1.271	1.273	1.286	1.280	1.291	1.296
EXPERIMENTAL	MEAN	24.032	24.055	24.104	24.127	24.169	24.262
	STD. ERROR	0.379	0.381	0.384	0.383	0.385	0.387
	S.E. (t)	0.667	0.671	0.676	0.674	0.678	0.682

* where 't' is at P= 0.05, and d.f. = N-1

Table 2. Statistics on daily shell lengths, in millimeters, of control and experimental group mussels.

STATISTIC	CONTROL			EXPERIMENTAL		
	REPLICATE 1 N=6	REPLICATE 2 N=9	AVERAGE N=15	REPLICATE 1 N=7	REPLICATE 2 N=8	AVERAGE N=15
MEAN	0.018	0.039	0.031	0.025	0.021	0.023
S.E.	0.005	0.012	0.008	0.009	0.003	0.004
(S.E.)(t)*	0.013	0.028	0.017	0.022	0.007	0.009
W**			0.002			0.003
MEAN	0.061	0.107	0.088	0.051	0.047	0.049
S.E.	0.018	0.014	0.012	0.012	0.011	0.008
(S.E.)(t)	0.046	0.032	0.026	0.029	0.026	0.017
W			0.174			0.627
MEAN	0.049	0.040	0.044	0.022	0.024	0.023
S.E.	0.012	0.010	0.007	0.009	0.010	0.006
(S.E.)(t)	0.031	0.023	0.015	0.022	0.024	0.013
W			0.471			0.003
MEAN	0.020	0.071	0.051	0.058	0.029	0.042
S.E.	0.020	0.012	0.012	0.016	0.009	0.009
(S.E.)(t)	0.051	0.028	0.026	0.039	0.021	0.019
W			0.686			0.043
MEAN	0.047	0.093	0.074	0.104	0.084	0.093
S.E.	0.019	0.021	0.015	0.012	0.016	0.010
(S.E.)(t)	0.049	0.048	0.032	0.029	0.038	0.021
W			0.463			0.702
MEAN INCREASE =			0.058	MEAN INCREASE =		0.046

* Where 't' is at p=0.05, and d.f. = N-1

** Shapiro-Wilks Statistic for normality: where W_{calc} >0.05, null hypothesis of normality accepted.

Table 3. Statistics on daily shell length increases by treatment; means in millimeters.

Source	DF	Mean Square	F Value	Pr > F
Treatment	1	0.00216508	0.77	0.3896
Treatment by Replicate	2	0.00930944	3.29	0.0532
Error	26	0.07351954		

Table 4. General linear models procedure, repeated measures analysis of variance. Test of hypothesis for between subjects effects.

DAY	REPLICATE 1		REPLICATE 2		DAILY AVERAGE
	MEAN	RANGE	MEAN	RANGE	
1	177	147 - 206	211	158 - 264	194
2	216	215 - 217	246	241 - 251	231
3	222	217 - 227	205	203 - 208	213
4	310	262 - 357	220	207 - 233	265
5	219	209 - 229	222	215 - 229	221
	OVERALL AVERAGE SPM = 225 ± 10.9 (S.E.)				

Table 5. SPM measurements (mg/l), replicates 1 and 2 of experimental group.

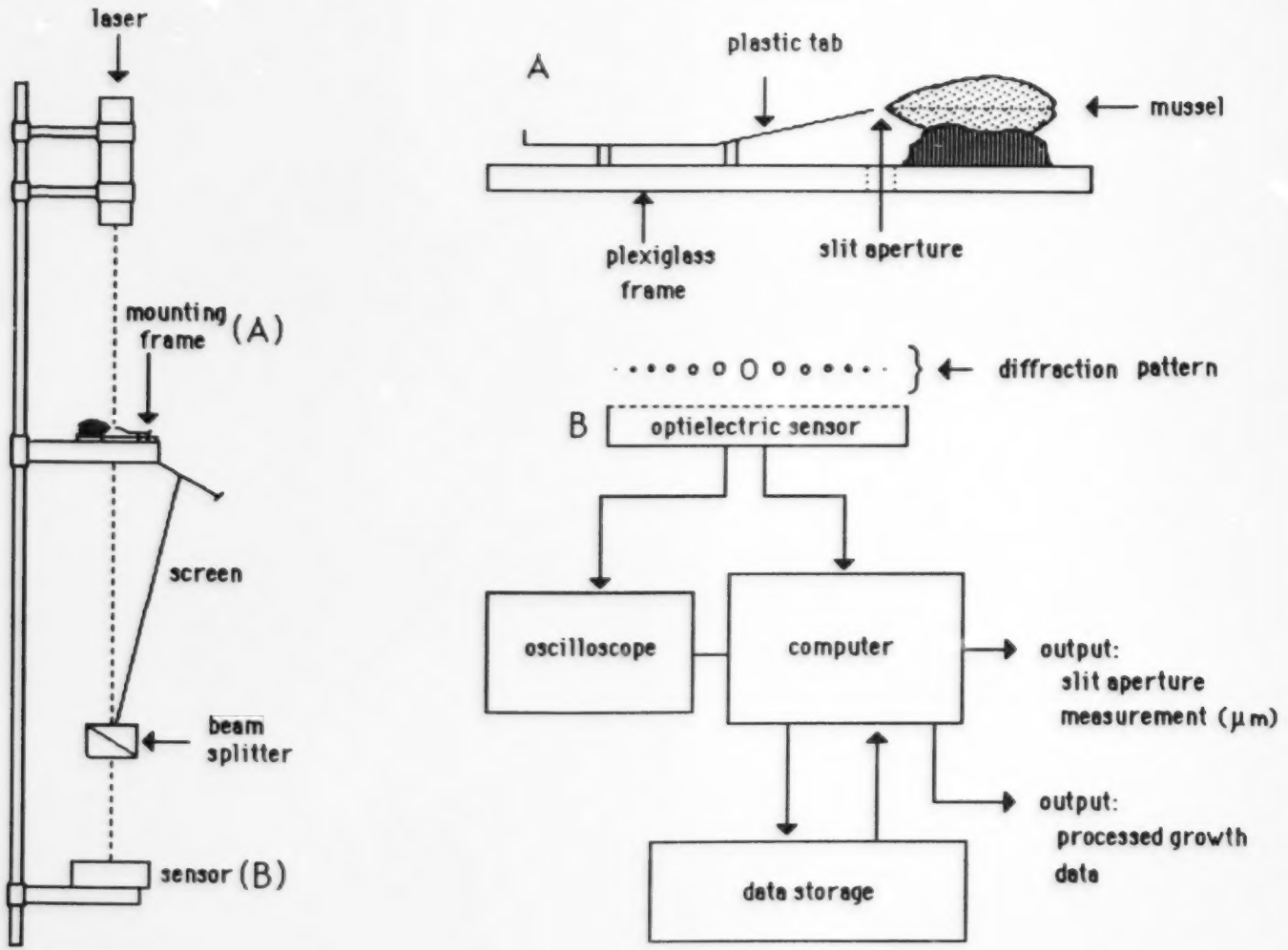

Figure 1. Design of laser diffraction system (Strømgren and Cary, 1984).

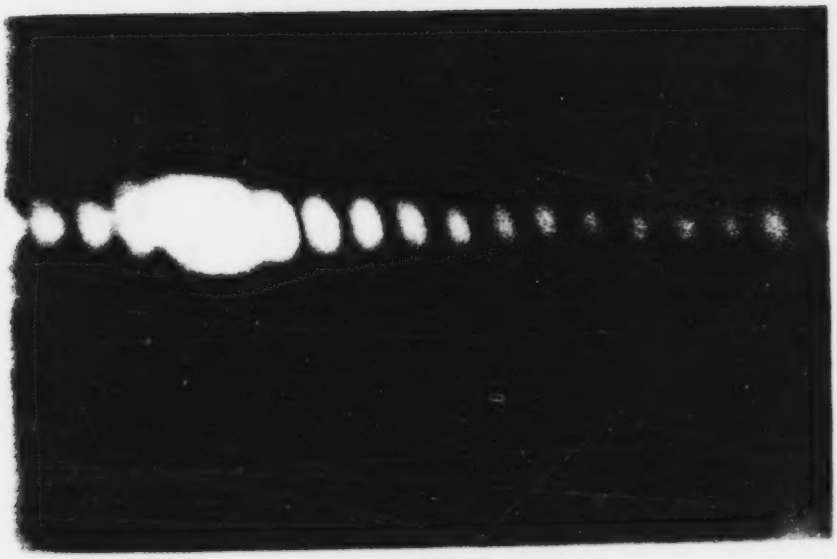

Figure 2. Example of laser diffraction pattern.

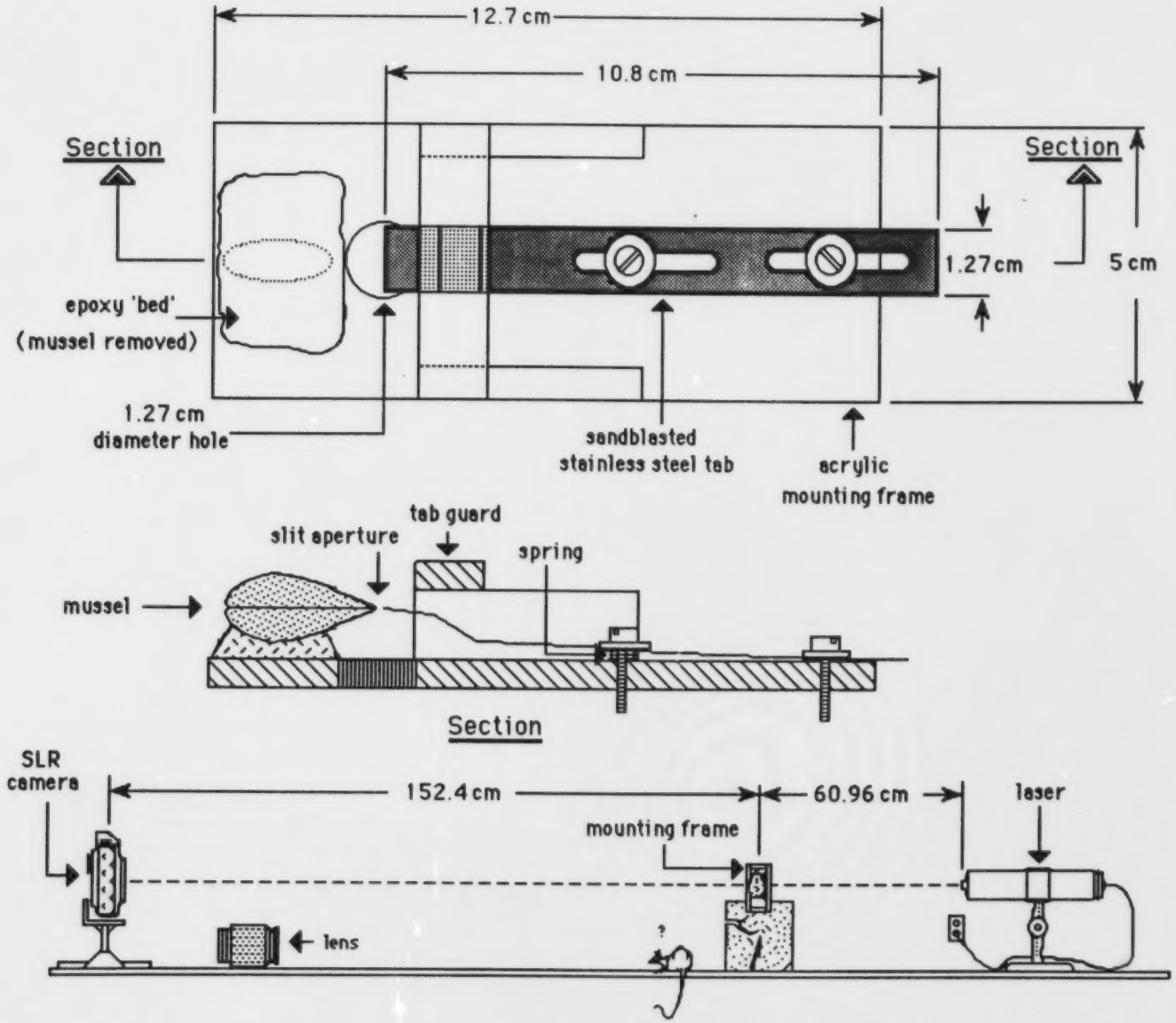

Figure 3. Design of laser diffraction system (Sushko and Freeman, 1991)

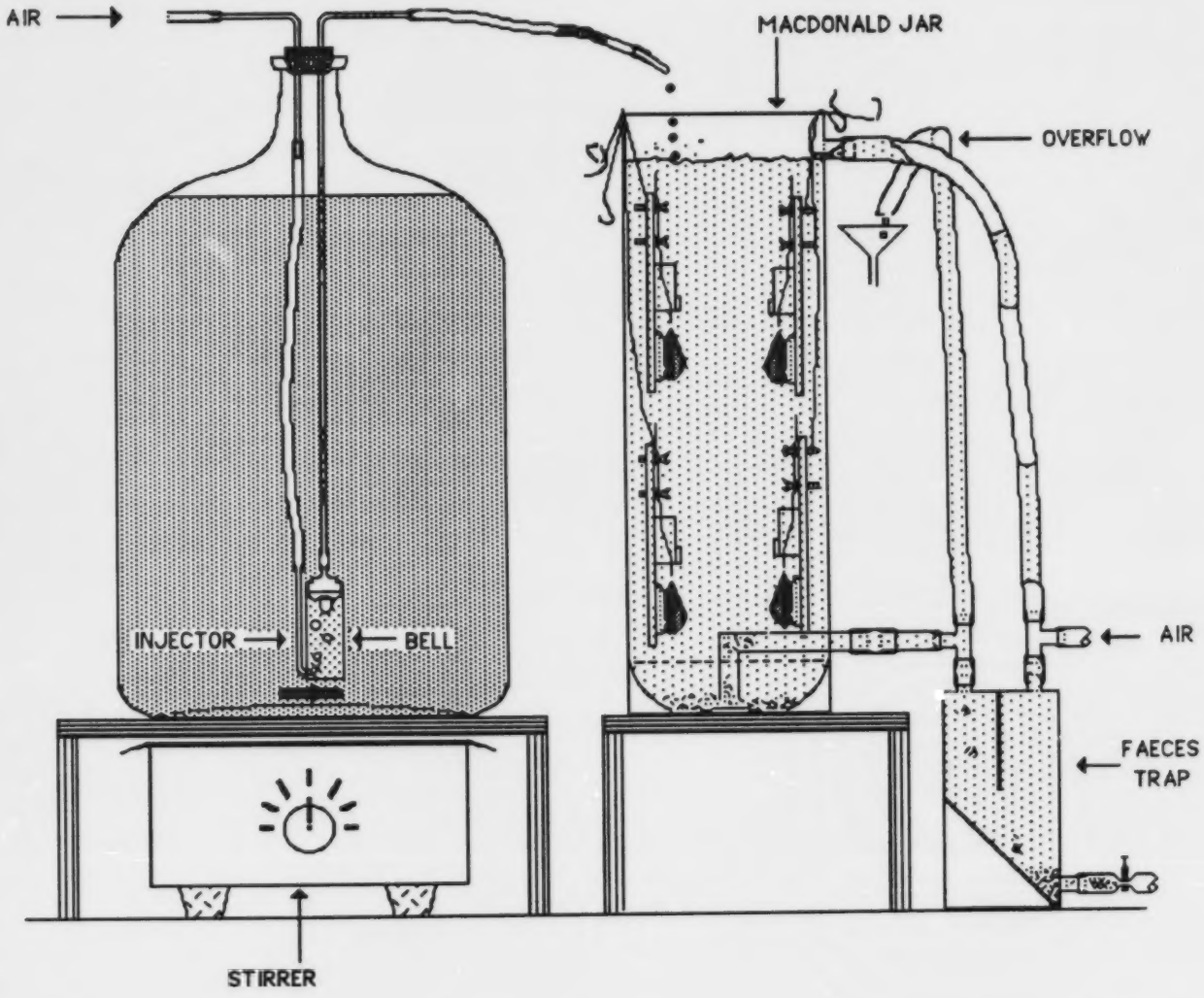

Figure 4. Food/sediment delivery unit and grazing chamber

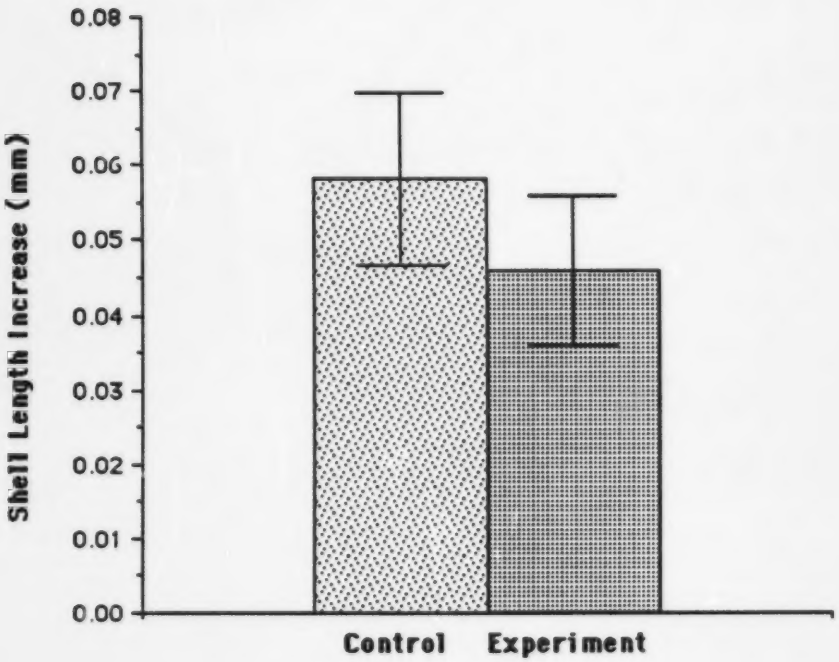

Figure 5. Mean shell length increases, both groups averaged over five days (Error Bars = S.E. x 't')

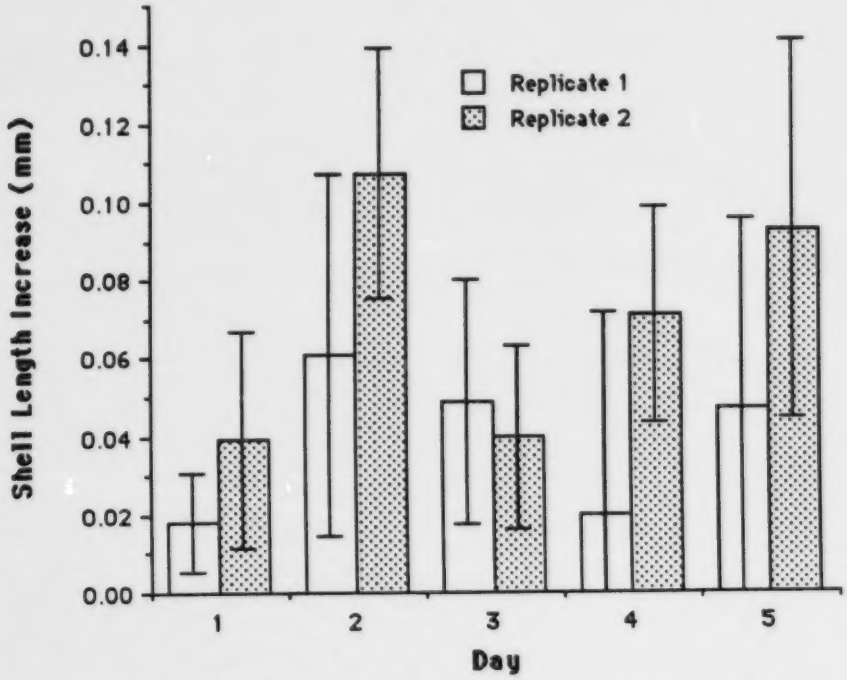

Figure 6(i). Mean daily shell length increases, treatment 1 (control) by replicate (Error Bars = S.E.x"t")

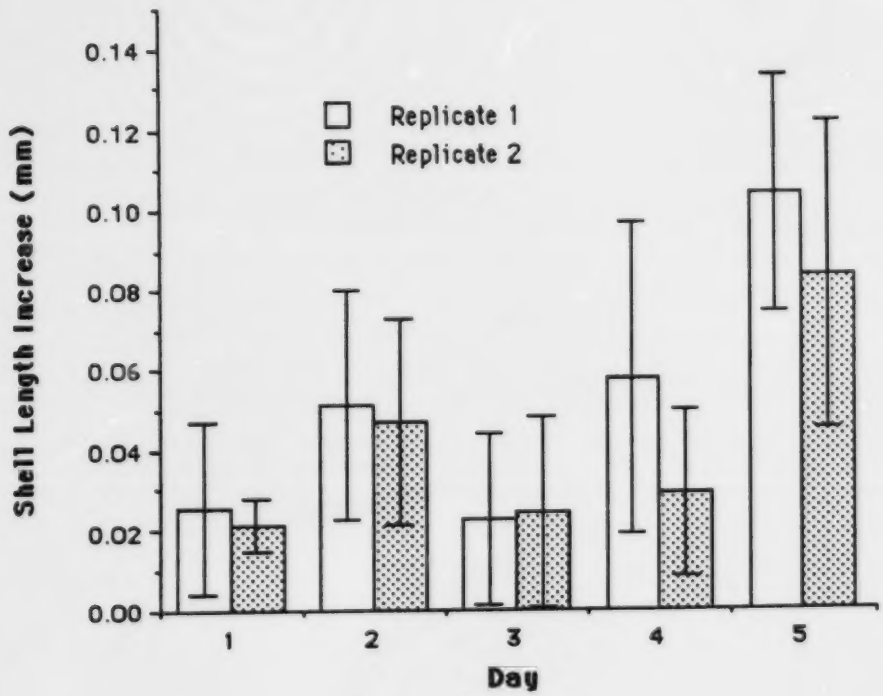

Figure 6(ii). Mean daily shell length increases, treatment 2 (experimental) by replicate. (Error Bars = S.E.x "t")

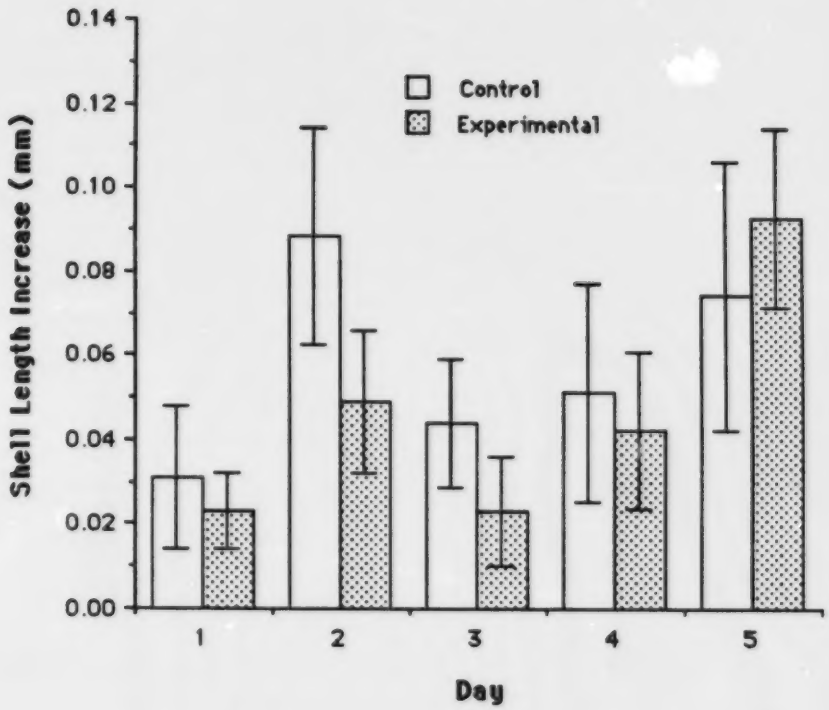

Figure 7. Mean daily shell length increases, treatment comparison.
(Error Bars = S.E.x"t")